CIRRUS CLOUD MODEL PARAMETERIZATIONS: INCORPORATING

REALISTIC ICE PARTICLE GENERATION

K. Sassen and G.C. Dodd
Department of Meteorology, University of Utah
Salt Lake City, UT 84112

D.O'C. Starr
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Recent cirrus cloud modeling studies (Starr and Cox, 1985; Starr, 1986) have involved the application of a time-dependent, two-dimensional Eulerian model, with generalized cloud microphysical parameterizations drawn from experimental findings. Employed in the model are a grid resolution of 100 m and a time step of 30 s. For computing the ice-versus-vapor phase changes (at 3-min intervals), the ice mass content is linked to the maintenance of a relative humidity with respect to ice (RHI) of 105%; ice growth occurs both with regard to the introduction of new particles and the growth of existing particles. To initiate ice particle formation in regions devoid of ice particles, a RHI of 120% is required. In a simplified cloud model designed to investigate the basic role of various physical processes in the growth and maintenance of cirrus clouds, these parametric relations are justifiable.

In comparison, the one-dimensional cloud microphysical model recently applied to evaluating the nucleation and growth of ice crystals in cirrus clouds (Sassen and Dodd, 1988) explicitly treated populations of haze and cloud droplets, and ice crystals within a 200 m height domain above cloud base, using 0.25-s time steps and specified updraft velocities. The model findings were used to infer a cloud droplet homogeneous freezing rate in compliance with aircraft and ground-based polarization lidar observations. Moreover, implications for ice particle formation outside the limited height domain of the model were suggested by the findings.

Although these two modeling approaches are clearly incompatible, the goal of the present numerical study is to develop a parametric treatment of new ice particle generation, on the basis of detailed microphysical model findings, for incorporation into improved cirrus growth models. For example, we can determine the relation between temperature and the relative humidity required to generate ice crystals from ammonium sulfate haze droplets, whose probability of freezing through the homogeneous nucleation mode are a combined function of time and droplet molality, volume, and temperature. Within cirrus clouds at temperatures colder than about -37°C, homogeneous drop freezing will most likely result from a decrease in molality as the droplet equilibrium size increases in response to increasing relative humidity, which can be caused by either enhanced updraft velocities or a decrease in water vapor competition effects (from ice crystal fallout). Molality dominates the haze droplet freezing process as a consequence of the very strong dependence of the freezing rate on drop temperature, which is modified by the freezing point depression as a function of drop molality. The

adjustment of haze droplets to new equilibrium sizes in an accelerating parcel occurs very rapidly.

As an example of this approach, in Fig. 1 we present the results of cloud microphysical simulations showing the rather narrow domain in the temperature/humidity field where new ice crystals can be generated. The three solid curves (a,b,c) represent the conditions under which equilibrium haze droplets of ammonium sulfate (with CCN masses and radii given in the figure caption) have an even chance of freezing homogeneously within typical cirrus growth model time steps--the relation $P_f(0,60) = 0.5$ is the probability that one-half of the equilibrium droplets will freeze within a 60-s time interval. The area beneath the three curves represents a reservoir of stable haze droplets; the curves themselves are both a sink for haze droplets and a source of ice crystals; and the area above the curves becomes, in effect, a forbidden domain of temperature and humidity. The boundary defined by the curves has the same significance as the 100% relative humidity barrier, which is rarely exceeded by more than a few percent in atmospheric clouds, that must be overcome to form clouds at temperatures warmer than about -37°C.

When viewed in this manner, it is clear that much higher ice supersaturations than recent modeling efforts have employed are required to produce ice crystals within the homogeneous nucleation temperature domain. We note, however, that the RHI = 150% value indicated in Fig. 1 for new ice particle generation is similar to that derived from cirrus uncinus studies by Heymsfield (1975) for populations of ammonium sulfate droplets. Ice particle nucleation within cirrus will be modulated by vapor competition effects from existing ice particles such that, as the relative humidity increases, the growth of the haze droplets that freeze first (i.e., the largest droplets) inhibits further nucleations from the remaining reservoir of haze droplets (formed from smaller CCN masses). Hence, depending on the CCN concentrations and size spectra, depletion of the largest haze particles present would, over time, require gradually increasing relative humidities in order to generate new ice crystals, as shown in Fig. 1 by the intersection of an isotherm with curves c through a.

These microphysical simulations point out the need for detailed CCN studies at cirrus altitudes and haze droplet measurements within cirrus clouds, but also suggest that a relatively simple treatment of ice particle generation, which includes cloud chemistry, can be incorporated into cirrus cloud growth models.

References
Heymsfield, A., 1975: Cirrus uncinus generating cells and the evolution of cirriform clouds. Part III: Numerical computations of the growth of the ice phase. J. Atmos. Sci., 32, 820-830.
Sassen, K. and G.C. Dodd, 1988: Homogeneous nucleation rate for highly supercooled cirrus cloud droplets. J. Atmos. Sci., 45, 1357-1369.
Starr, D.O'C., 1986: Cirrus clouds: Effects of microphysical composition and radiative processes. Preprints (Vol. 3), Conference on Cloud Physics, Snowmass, CO, Am. Meteor. Soc., J187-J190.
Starr, D.O'C. and S.K. Cox, 1985: Cirrus clouds. Part I: A cirrus cloud model. J. Atmos. Sci., 42, 2663-2681.
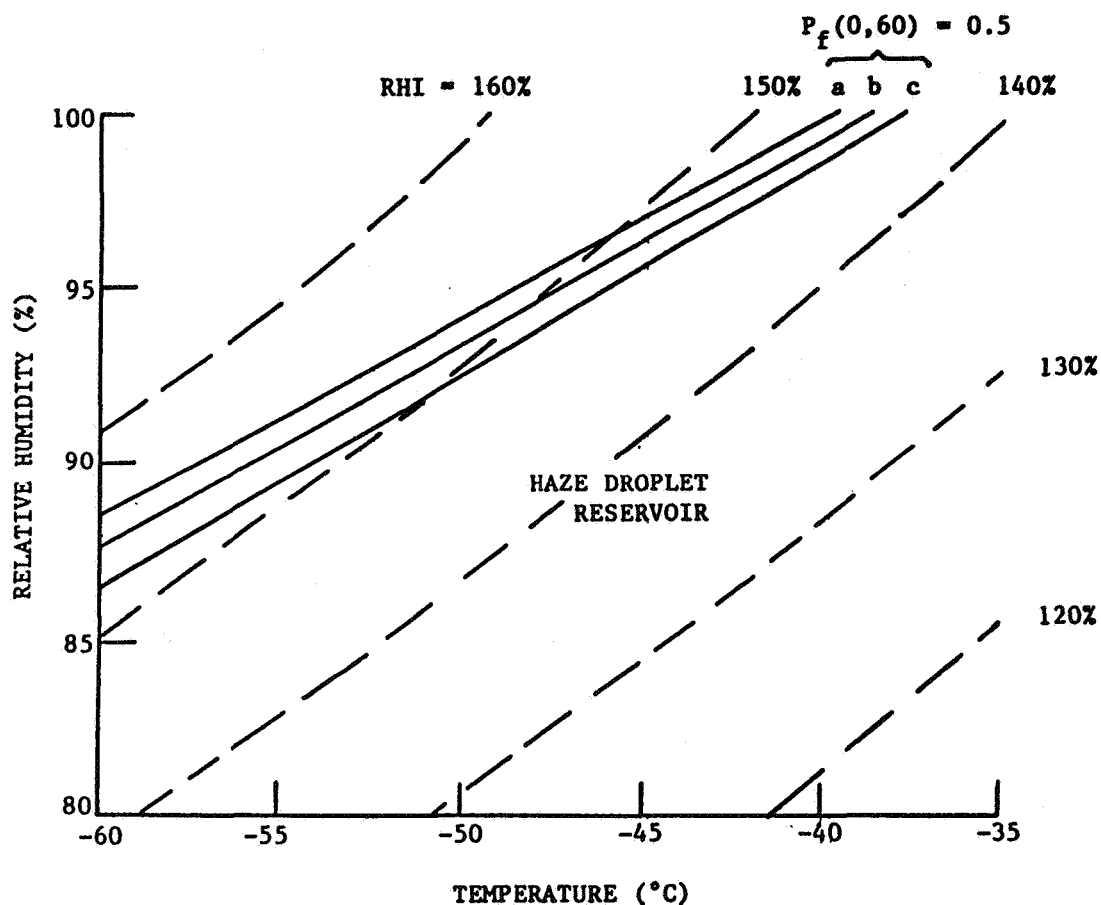
Fig. 1 A schematic representation of the temperature dependency in relative humidity values (with respect to water) needed to nucleate new ice crystals from the homogeneous freezing of haze droplets. The three curves are for ammonium sulfate cloud condensation nuclei (CCN) masses and radii of a) 10^{-14} g and 0.11 μm; b) 10^{-13} g and 0.24 μm; and c) 10^{-12} g and 0.51 μm. The dashed curves give relative humidities with respect to ice (RHI). The homogeneous freezing rate derived by Sassen and Dodd (1988) and a constant pressure of 300 mb have been used in the calculations.